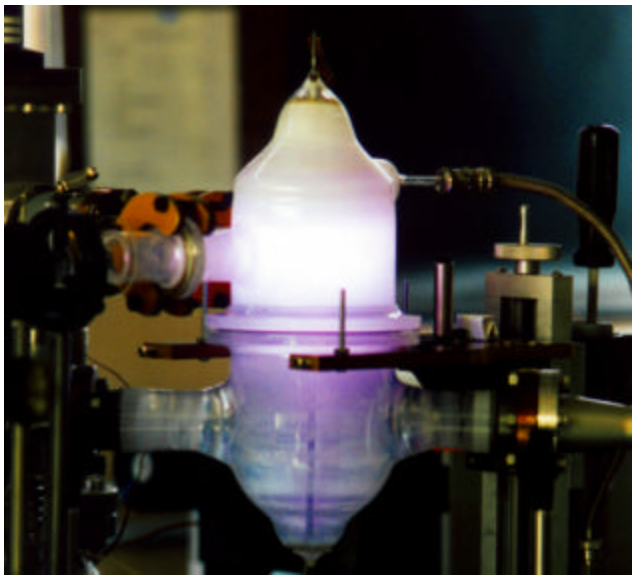
ACCOMPLISHMENT REPORT

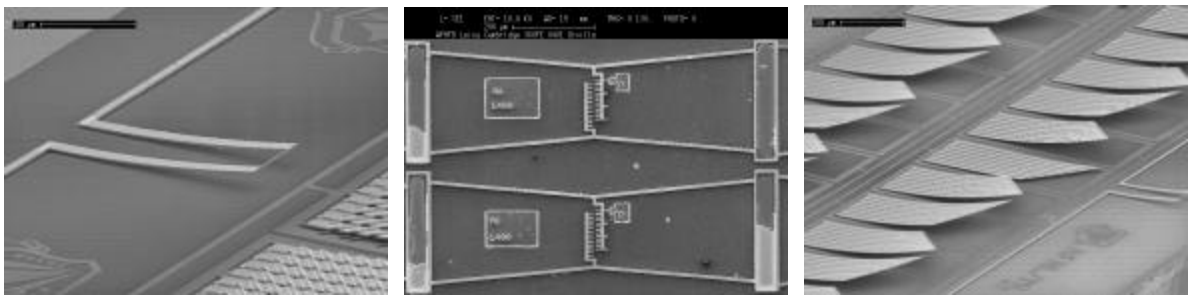
PROPULSION DIRECTORATE
June 2000

RESEARCH YIELDS ESSENTIAL PLASMA ETCHING TECHNIQUES: An important objective of recent research within the Propulsion Directorate's Power Division (AFRL/PRP) has been to develop a reliable, repeatable manufacturing process for wide bandgap electronic devices and MEMS (Micro Electro Mechanical Systems). Subsequent research in this area has resulted in the successful development of advanced plasma etching techniques for silicon carbide (SiC) devices. Industry currently relies on silicon (Si) semiconductors for many electronic applications; however, DoD requirements dictate the use of radiation hardened longer life and higher durability semiconductor materials like SiC. The chemical inertness of these materials makes it difficult to cut or etch straight edges with a high degree of accuracy. AFRL/PRP researchers developed a generic process that affords a manageable method for etching SiC, and this process includes a tool and operating parameters to obtain high anisotropic etch rates with excellent surface smoothness. DoD applications for this new etching technique include power devices, pressure and temperature sensors, and SiC high temperature integrated circuits. This technique significantly enhances the ability to realize SiC power electronic devices capable of satisfying More Electric Aircraft (MEA), space based radar (SBR), and directed energy weapons (DEW) requirements. Numerous commercial applications for this technology have been identified in the power generation, automotive, and medical industries. Opportunities to collaborate with AFRL/PRP on this technology are available for both public and private sector organizations. The goal of this collaboration is to scale-up the current process and ultimately provide affordable devices that meet stringent DoD operating parameters. (B. Ganguly, AFRL/PRPS, (937) 255-2923)



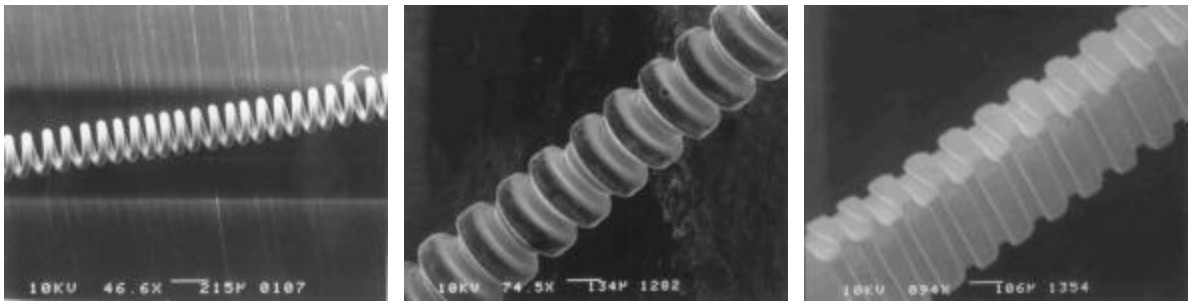
Etching SiC using SF_6 diluted with helium

Chamber used for plasma processing



Sample MEMS

PATENT ISSUED FOR MANUFACTURING MICROTUBES: On 9 May 2000, a United States Patent (#6,059,001) titled "Apparatus for Manufacturing Microtubes with Axially Variable Geometries" was granted to the Air Force. One of the inventors of this patent, Dr. Wesley Hoffman, is a researcher in the Propulsion Directorate's Propulsion Materials Application Branch (AFRL/PRSM). This invention describes a technique for manufacturing microtube devices which have circumferential geometries repeated either uniformly or non-uniformly along the tube or device axis with sub-micron precision. Microtube technology has significant potential for both military and commercial applications. Microtubes can be constructed from a wide range of materials such as metals, ceramics, glasses, polymers, and layered combinations. Furthermore, the composition and geometry of the tubes can be precisely controlled to suit a given application. Among the applications envisioned for this technology are accelerometers manufactured as sensors for air-bag actuation, micro-fluidic devices, biosensors for glucose, and disposable blood pressure sensors that are inserted into the body. (W. Hoffman, AFRL/PRSM, (661) 275-5768)
The complete text of U.S. Patent #6,059,001 can be found at the following website:
http://164.195.100.11/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=/netahtml/srchnum.htm&r=1&f=G&l=50&s1='6059001'.WKU.&OS=PN/6059001&RS=PN/6059001



Sample microtubes

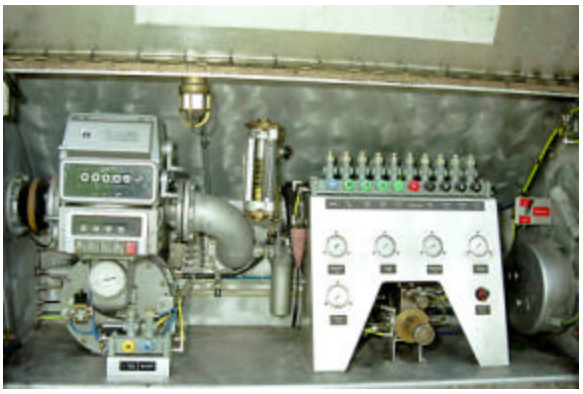
TRF UPGRADED TO SUPPORT FUTURE F119 TESTING: The Propulsion Directorate's Turbine Branch (AFRL/PRTT), in cooperation with the Technology Evaluation Branch (AFRL/PRTE) and AdTech, recently accomplished the first step toward a future test of the F119 turbine. Two cryogenic tanks were installed in the Turbine Research Facility (TRF) at Wright-Patterson AFB with the purpose

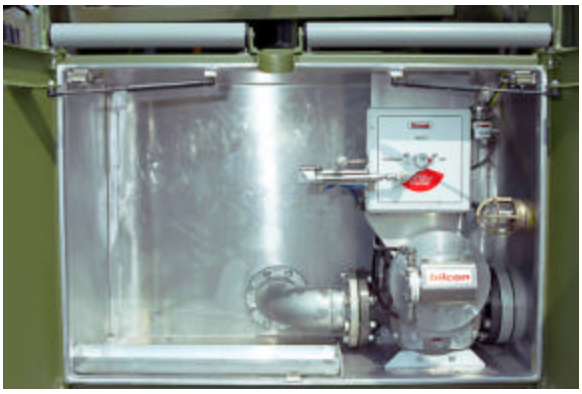
of running the F119 turbine in a cooled configuration. The tests on the F119 turbine will provide scaled film cooling flows to the turbine. Due to scaling in the TRF, it is necessary to run a cryogenic cooling loop to match temperature ratios. The cooling system is able to feed both the vane and rotor with independent cold flows, and it has been designed to function over a wide range of flow rates. The cooling system will help researchers understand the behavior of cooled turbines from both aerodynamic and heat transfer points of view. This will lead to a better understanding of current Integrated High Performance Turbine Engine Technology (IHPTET) turbines and advanced turbine engines. (2Lt D. Zeno, AFRL/PRTT, (937) 255-6768)

New cryogenic tanks installed in PR's Turbine Research Facility

DENMARK SUCCESSFULLY DEMONSTRATES +100 FUEL ADDITIVE: In May 2000, the Royal Danish Air Force (RDAF) hosted delegates from the US and other NATO allies to participate in their +100 program review and witness the first engine teardown of a Danish engine operating on +100. The +100 fuel additive was developed by the Propulsion Directorate's Fuels Branch (AFRL/PRSF) in an effort to minimize maintenance associated with fuel degradation in aircraft fuel systems. The RDAF began operating with F-34+100 during the fall of 1999 (Note: F-34 is the NATO designation for JP-8). The system used by the RDAF for injecting the +100 additive into the fuel differs from the configuration used by the USAF. Due to NATO cross servicing requirements, the RDAF has chosen an injection system that injects the additive as the fuel is loaded onto the plane. One refueling truck can service two planes at one time, injecting the additive in none, one, or both aircraft. The system includes safety measures that prevent accidental additizing of the fuel. During the visit, two F-16 engines were available for examination and boroscopic inspection. One of the engines had been operated on F-34 without the +100 additive while the other had been operated on F-34+100 since fall 1999. The differences between the two engines were striking, clearly demonstrating the advantages of the +100 additive. The RDAF showed great satisfaction with the results obtained using the +100 additive. The positive results demonstrated now by two NATO allies (i.e., the US and Denmark) sparked interest among the other countries that attended the meeting, including Belgium, Canada, Germany, Norway, and the United Kingdom. (P. Liberio, AFRL/PRSF, (937) 255-6918)

Part of the multi-national team that aided Denmark's conversion to F-34+100





Hardware used for supplying F34+100 fuel

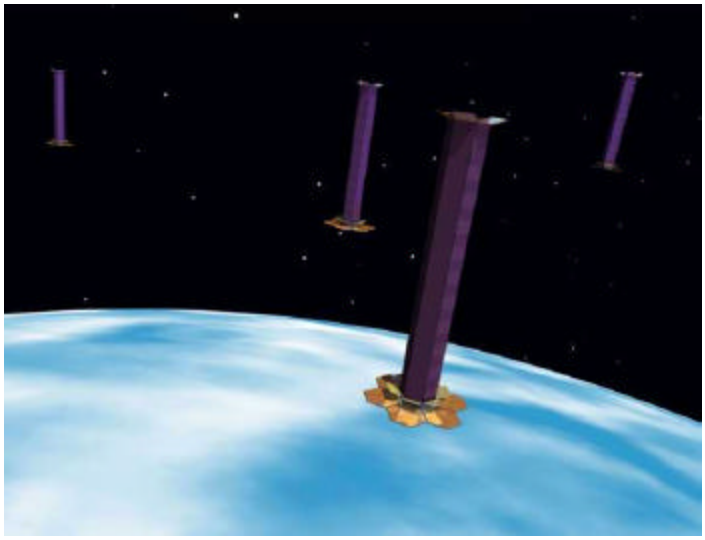
TITUS WINS ENVIRONMENTAL AWARD: TSgt John E. Titus, who works at the Propulsion Directorate at Edwards AFB, California, recently became the first recipient of the AFRL Environmental Safety and Occupational Health (ESOH) Professional of the Year Award. Col James Heald, AFRL Vice Commander, presented the award to TSgt Titus at the AFRL ESOH Cross Training Workshop in April at Wright-Patterson AFB. Since 1998, TSgt Titus has worked for PR in the Ground and Explosive Safety Programs area. These programs protect the 244 government employees and 500 contractor personnel assigned to AFRL at Edwards AFB. In addition, he evaluates experimental research and development projects for safety controls and monitors test operations at 30 test facilities within the lab's 65 square mile rocket research facility. TSgt Titus developed a tracking system for monitoring discrepancies on a monthly basis, which has been credited with encouraging managers to take action to correct safety deficiencies. PR saw a 64 percent drop in the number of ESOH problems in a four-month period; eliminating numerous safety hazards and potential injuries. As a member of Safety Review Boards and Test Control Teams, TSgt Titus provided guidance to the hazard analysis

TSgt Titus receives the ESOH Professional of the Year Award from Col Heald

process, which corrected and eliminated safety and explosive hazards with many high profile test programs. In addition, TSgt Titus teaches several safety training classes. He has also used closed circuit television, monthly bulletins, and Intranet web pages to distribute ESOH information and increase safety awareness throughout PR. (J. Pearce, AFRL/PRO, (937) 255-5451)

for more detail, see the Propulsion Directorate's press release titled "Propulsion Professional Receives Laboratory Award" at http://www.pr.wpafb.af.mil

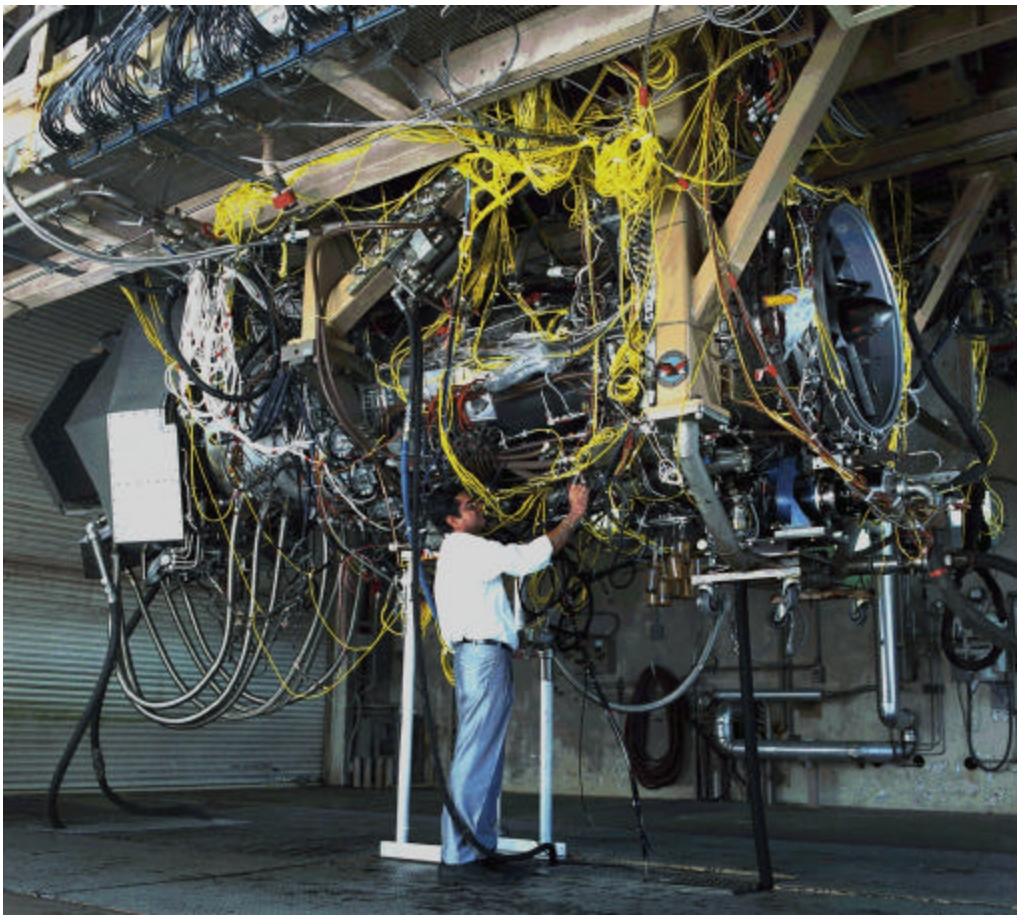
THRUSTERS FOR TECHSAT 21 PROPULSION SYSTEM TESTED: Potential bidders on the TechSat 21 Propulsion Subsystem Development were recently invited to demonstrate their capabilities. Several bidders submitted thrusters for evaluation, and in-house testing of these thrusters was completed at the Propulsion Directorate's Rocket Engine Division (AFRL/PRR) at Edwards AFB in May 2000. During this testing, performance data on the candidate thrusters was obtained. On 8 May 2000, the proposals for the TechSat 21 Propulsion Subsystem Development were received, and these proposals are currently being evaluated. The TechSat 21 Program has the overall goal of developing a constellation of satellites that fly in formation to perform a surveillance mission. This concept is motivated by a desire to reduce the cost and weight of space systems. Micro-propulsion is one of the five major research areas being pursued under the program. The cluster of satellites fly in formation with relatively little propulsive impulse needed to maintain the formation. The main task of the propulsion system is to allow the satellite constellation to be reconfigured or optimized for a particular mission. Propulsion studies will focus on investigations of micro-electric, micro-chemical, and micro-fluidic propulsion systems. The emphasis is on high specific impulse (efficiency), medium and low thrust, and long life/space durability



Artist's concept of a satellite constellation

aspects. (L. Quinn, AFRL/PRR, (661) 275-5630)

IHPTET JTDE TO TEST FAN DAMAGE TOLERANCE: High Cycle Fatigue (HCF) is a major factor negatively impacting safety, operability, and readiness of high performance turbine engines. A National HCF Program was established with the goal of reducing HCF related non-recoverable in-flight shutdowns by 50 percent and virtually eliminating HCF related Class A mishaps. This activity is directed by the Propulsion Directorate and includes participation from the Navy, NASA, and industry. Pratt & Whitney will begin HCF testing of their Integrated High Performance Turbine Engine Technology (IHPTET) Joint Technology Demonstrator Engine (JTDE) in June 2000. The JTDE is configured with an F119 fan to validate the Foreign Object Damage (FOD) tools developed under the HCF Initiative. Controlled FOD will be introduced into the leading edge of the first fan airfoils and then engine tested to initiate cracks. Some fan airfoils are Laser Shock Peened (LSP) in order to assess the increased damage tolerance when applied to an Integrally Bladed Rotor (IBR). The data from this test will transition to both the F-22 and Joint Strike Fighter (JSF) Programs via the signed Technology Transition Plan. (M. Dale, AFRL/PRTP, (937) 255-2767)



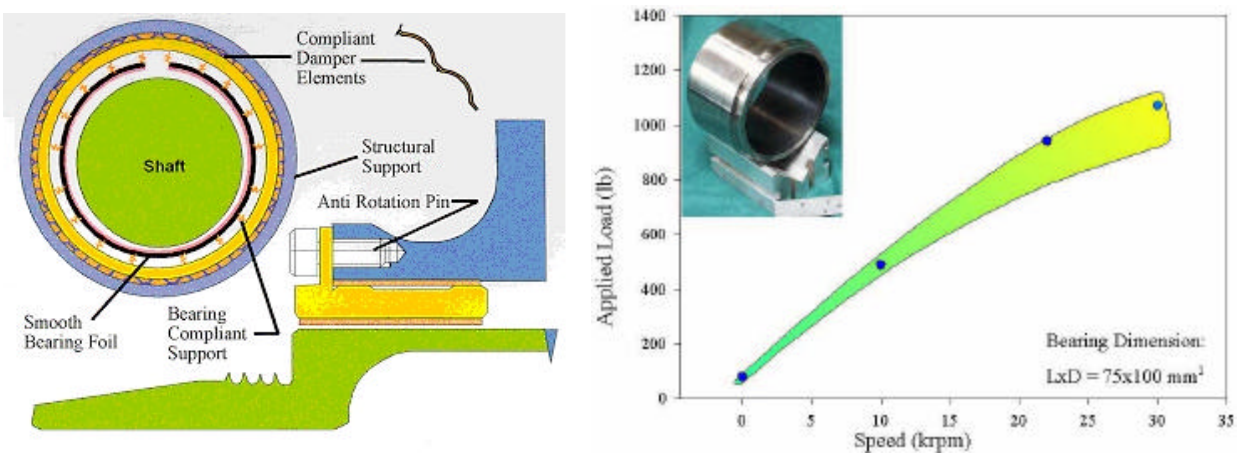
Pratt & Whitney's Joint Technology Demonstrator Engine

POLYMER GROUP GARNERS FLC TECH TRANSFER AWARD: Members of the Propulsion Directorate's Polymer Working Group recently attended the Federal Laboratory Consortium (FLC)

conference in Charleston, South Carolina, to accept an award for technology transfer. The recipients of the award (Dr. Shawn Phillips, Dr. Rusty Blanski, Dr. Tim Haddad, Pat Ruth, and Justin Leland) were honored for their efforts to transfer POSS (polyhedral oligomeric silsesquioxanes) nanotechnology. This technology is of great interest because POSS additives can radically upgrade the thermal and physical properties of most plastics. Furthermore, POSS is easily incorporated into common plastics via copolymerization or blending thus requiring little alteration to existing manufacturing processes. In less than 1½ years since establishing a CRADA with Hybrid Plasti cs to transfer POSS nanotechnology, the price of many POSS monomer feedstocks has decreased by a factor of four to five. Production of the POSS materials is now approaching 200 kilograms per year, which is an order of magnitude higher than the production rate in 1998. Hybrid Plastics is also considering starting a production plant for multi-ton production. POSS demand has increased rapidly over the last 1½ years, and independent market analysis predicts the need for multi-ton quantities of POSS by FY02. Hybrid Plastic has recently discovered a route for making a functionalizable POSS feedstock for under $100/pound. (S. Phillips, AFRL/PRSM, (661) 275-5416)

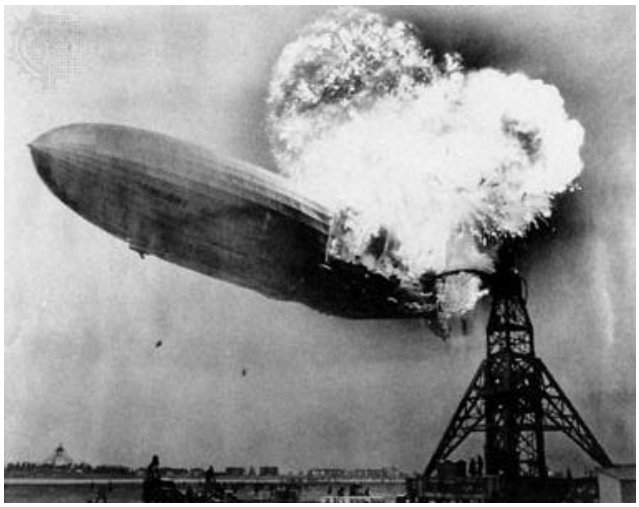
FLC Technology Transfer Award winners (from L to R, Leland, Blanski, Phillips, Ruth & Haddad)

PROGRAM INITIATED TO DEVELOP FOIL BEARINGS: On 12 May 2000, Mohawk Innovative Technology, Inc (MiTi) was awarded a Phase II SBIR with the Propulsion Directorate's Lubrication Branch (AFRL/PRSL). This program, titled "Compliant Foil Bearings for Advanced Oil-Free Turbomachinery," has the objective of developing high-speed foil bearings for advanced turbine engines. Compliant foil bearings support the rotor on a hydrodynamic air film, thus eliminating the need for rolling element bearings and the associated liquid lubrication system. Potential benefits for turbomachinery include increased rotational speed and operating temperature, improved storability, reduced maintenance, and a 30 percent reduction in cruise missile engine cost and weight. This program is structured to allow hardware developed in a successful SBIR Phase II effort to be demonstrated in an Integrated High Performance Turbine Engine Technology (IHPTET) demonstrator engine. The demonstrator currently targeted for this foil bearing technology is Williams International's IHPTET Phase III Joint Expendable Turbine Engine Concept (JETEC) demonstrator engine. (M. Wagner, AFRL/PRSL, (937) 255-7406)



Schematic of a foil bearing (left) and measured bearing performance (right)

PR SCIENTIST APPEARS ON PBS: Lawrence Walko, Chief of the Propulsion Directorate's Power Systems Branch (AFRL/PRPS), recently appeared in the PBS series "Secrets of the Dead." Mr. Walko appeared in an episode titled "What Happened to the Hindenburg?" This program presents an alternative to the popular theory that the 1937 Hindenburg disaster was caused by the ignition of flammable hydrogen. Instead, the proposed theory states that the skin used to cover the Hindenburg, which was doped with a combination of chemicals resembling the solid rocket fuel used for the Space Shuttle, ignited due to a high voltage static discharge. In the segment of the program featuring Mr. Walko, he explained how the Hindenburg accumulated a static charge on its skin simply by flying through the atmosphere. Later in the program, it was theorized that this static charge might have been of sufficient magnitude to ignite the Hindenburg's skin. Mr. Walko's appearance in this program serves to highlight the world-class personnel and technical expertise available in the Propulsion Directorate. (J. Pearce, AFRL/PRO (UTC), (937) 255-5451)
Further details on this program are available at
http://www.pbs.org/wnet/secrets/html/e3-menu.html



NEW EFFORT TO PRODUCE HIGH ENERGY DENSITY CAPACITORS: Present capacitor dielectric materials such as polyester and polypropylene are not suitable for newer applications because of their poor energy densities. However, one candidate material, polyvinylidene fluoride (PVDF), has a very high energy density and can easily be manufactured in thin films and wound into capacitors. Unfortunately, PVDF's poor electrical properties and high cost presently limit its use in capacitors. Under combined Ballistic Missile Defense Organization (BMDO) SBIR Phase I and FasTrack funding, Lithium Power Technologies, Inc. (LPTI) has designed new copolymer film capacitor materials that exploit the high energy density of PVDF and are electrically stable. LPTI was recently awarded a Phase II SBIR program to continue this work. When fully developed, a capacitor using PVDF will have energy densities more than three times higher than those on the market today, which will reduce unit energy cost by 50 percent in certain applications. This translates into a six-fold cost effectiveness competitive advantage. This technology can also extend capacitor life by several hundred thousand cycles. In the Phase I program, LPTI overcame PVDF's barriers by combining it with other polymerics in a solid-solution copolymer blend having excellent insulator properties. Capacitor tests have demonstrated an energy density of 5 J/cm^3, and LPTI will focus on increasing energy density to greater than 8 J/cm^3 during the Phase II effort. Though still in the early stages of research and development, LPTI has already established a small manufacturing facility for limited scale production and has co-investment funds in hand. LPTI plans to introduce the technology to the medical community for external and implantable defibrillators, exploring such applications with several medical equipment manufacturers. (S. Fries Carr, AFRL/PRPE, (937) 255-6016)

Dr. Robert C. Corley

ROCKET PROPULSION PIONEER RETIRES: Dr. Robert C. Corley, the Senior Scientist at the Propulsion Directorate's facilities at Edwards AFB, retired from government service on 2 June 2000. Dr. Corley spent more than 37 years at the lab in a variety of positions while leaving a trail of scientific accomplishments behind him. Among his accomplishments were propellant formulations that have minimal smoke in their exhaust, which helps tactical rockets to surprise their target. He also led efforts to identify and formulate solid propellant binders, the materials that hold oxidizers and fuel together in a rocket, that are stable, strong, and able to withstand very cold temperatures. He is credited with pushing the development of the resulting polymer known as hydroxyl terminated polybutadiene (HTPB), which is currently used in almost all US and foreign solid rocket weapon systems. Following these efforts, he continued his leadership of research to enhance rocket propellant performance. That research, called High Energy Density Matter (HEDM), has already provided some world-firsts by the lab. His leadership skills were again applied to the Integrated High Payoff Rocket

Propulsion Technology (IHPRPT) Program, a national program involving the military services, NASA, and the rocket industry to enhance and double rocket propulsion performance and reliability while reducing costs. His leadership and technical expertise, evidenced by more than 25 technical publications and eight patents or inventions, have significantly advanced the nation's rocket propulsion technology. (L. Quinn, AFRL/PRR, (661) 275-5630)
for more detail, see the Propulsion Directorate's press release titled "Research Pioneer Retiring" at http://www.pr.wpafb.af.mil

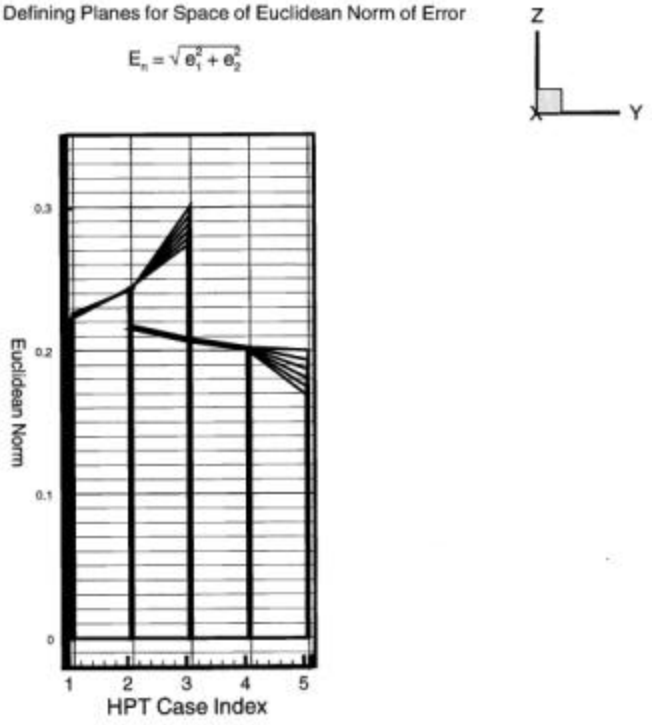
ZIEGLER WINS BEST PAPER AWARD: Capt Dustin Ziegler of the Propulsion Directorate's Aerophysics Branch (AFRL/PRSA) recently received notification that he was selected to receive a Best Paper award for his paper titled "Interceptor Sensor Self-Blinding Analysis of Four Candidate Propellants." Capt Ziegler presented this paper at the 1999 American Institute of Aeronautics and Astronautics (AIAA)/Ballistic Missile Defense Organization (BMDO) Technology Readiness Conference. The Best Paper award will be presented to Capt Ziegler at the 2000 AIAA/BMDO Technology Readiness Conference in July. (J. Levine, AFRL/PRSA, (661) 275-6179)

Captain Dustin Ziegler

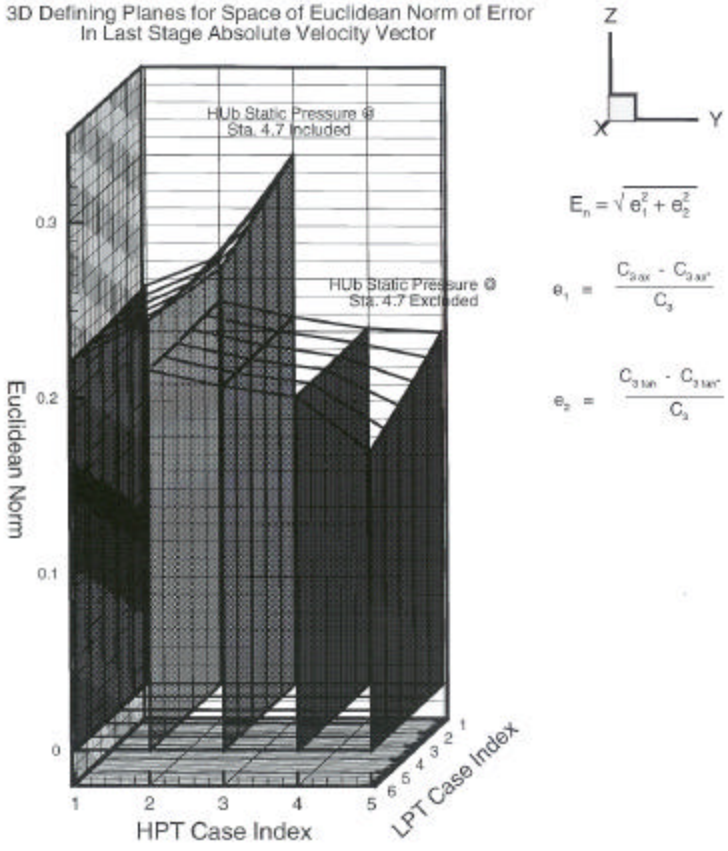
INNOVATIVE ANALYSIS FILLS VOID IN TEST DATA: Unique analysis by researchers in the Propulsion Directorate's Turbine Engine Division (AFRL/PRT) is providing a powerful tool for interpreting engine test data. The XTE66/1 demonstrator engine is equipped with a vaneless, counter-rotating low-pressure turbine stage. For recent tests, sufficient instrumentation could not be incorporated between the high and low-pressure turbines because intrusion of the required probes would cause excess buffeting on the vaneless turbine blades. An innovative meanline analysis of the hot section of this engine was incorporated to determine the mean velocity triangles and stage performance for each of the turbine stages. However, because of engine instrumentation survivability and calibration problems, there was insufficient data to determine a unique solution for the turbine stages. Cooled, transonic turbines are not well enough characterized by existing CFD techniques to sufficiently reduce the uncertainties and diagnose all engine performance problems. However, using the mean exit velocity triangle for the last turbine stage it was possible to construct the Euclidean Norm of the velocity triangle error over the domain of viable mean gas path solutions. The combination of the meanline and error analysis methodologies has reduced the uncertainty in the probable set of physically viable solutions that match the available engine data. By taking advantage of this approach, meanline and CFD analysis can be calibrated to the most probable physical solutions to further reduce the performance uncertainties. This innovative analysis methodology provides a powerful tool in interpreting data with missing or inaccurate information. (R. Gray, AFRL/PRTT, (937) 255-3150)

3D Defining Planes for Space of Euclidean Norm of Error

$$E_n = \sqrt{e_1^2 + e_2^2}$$



3D Defining Planes for Space of Euclidean Norm of Error
In Last Stage Absolute Velocity Vector



$$E_n = \sqrt{e_1^2 + e_2^2}$$

$$e_1 = \frac{C_{3ax} - C_{3ax'}}{C_3}$$

$$e_2 = \frac{C_{3tan} - C_{3tan'}}{C_3}$$